Diaphragm for an Integrator Unit

Related application

        This application is a continuation application of

5   international patent application number PCT/EP 02/08180,

filed July 23, 2002, and claiming priority from German patent

application 101 38 847.0, filed August 15, 2001, the entire

content of said applications being incorporated herein by

reference.

10   Field of the Invention

        The invention relates to a diaphragm having a diaphragm

opening with the diaphragm being especially for an integrator

unit of a microlithographic projection exposure system.

Background of the Invention

15   Diaphragms of the above kind in illumination systems for

microlithographic projection exposure systems are known, for

example, from United States Patent 5,473,408. In the

illumination system shown here for a microlithographic projection

exposure system, a reflecting diaphragm having a

20   circularly-shaped diaphragm opening is mounted directly ahead of

a rod integrator. On the one hand, light can enter into the rod

integrator via the diaphragm opening and, on the other hand,

light, which is reflected back from the reticle and again arrives

in the rod integrator, is reflected an additional time at the

25   reflecting diaphragm surface and is again supplied to the useful

light. The diaphragm opening has a diameter which is

significantly less than the height of the rod.

        United States Patent 5,601,733 likewise discloses diaphragms

which are mounted forward of a rod integrator. As shown in

30   United States Patent 5,473,408, the diaphragms are provided with

1

a reflecting surface on the side, which faces toward the rod

integrator, in order to again supply to the useful light the

light which is reflected back into the rod integrator from the

illumination system. A laser having a low "etendue" (phase space

5   volume) is used as a light source. For this reason, the light

can be focused with the condenser optics onto the diaphragm so

that the light passes through the diaphragm opening without

vignetting and the diaphragm opening has a diameter as small as

possible.

10   Illuminating systems for microlithography with rod

integrators are also disclosed in United States Patent 5,675,401.

A mercury high pressure lamp is used here as a light source. In

addition to a virtual spherically-shaped emission characteristic,

such light sources have a finite expansion so that they have a

15   significantly greater etendue compared to laser light sources.

In United States Patent 5,675,401, a condenser optic focuses the

light onto the entry surface of the rod integrator and generates

a light spot there. This light spot is round as long as the

light source has an expansion, which is rotationally symmetrical

20   to the optical axis, and the optical components in the condenser

optic have rotationally symmetrical optical effects. Precisely

in wafer scanners, rod integrators are used whose entry surface

has a high aspect ratio of rod width to rod height, for example,

an aspect ratio of 2:1 or greater. Here, it can happen that the

25   expansion of the light spot is greater than the height of the

rod. This leads to the situation that the light is vignetted.

As a rule, however, the ray angles, which occur at the entry

surface, are dependent upon the spacing from the optical axis.

For this reason, the vignetting leads to a so-called elliptical

30   pupil illumination. An elliptical pupil illumination is

2

understood to mean the intensity distributions in the pupil
planes which, in the quadrants arranged about a horizontal axis,
have a greater total intensity than in the quadrants arranged
about a vertical axis and therefore lead to a different

5   resolution capacity for horizontal and vertical structures in the
imaging of horizontal and vertical structures with projection
objectives used in microlithography.

Summary of the Invention

        In view of the above, it is an object of the invention to

10   improve illuminating systems incorporating rod integrators.

        The integrator unit of the invention is for a
microlithographic projection exposure system defining a beam path
along which light passes in a light direction. The integrator
unit includes: a rod integrator arranged in the beam path; a

15   diaphragm mounted in the beam path forward of the rod integrator
with respect to the light direction; and, the diaphragm
including: a diaphragm body; the diaphragm body having a
diaphragm opening formed therein; the diaphragm opening being
symmetrical to a first symmetry axis extending in x-direction;

20   the diaphragm opening having widths in the x-direction which are
dependent upon a distance (y) from the first symmetry axis; and,
the widths being greater than or equal to the width of the
diaphragm opening at $y = 0$.

        The diaphragm defined above is arranged in the light

25   direction ahead of the rod integrator. With this diaphragm, the
light spot on the entry surface of the rod integrator can be so
vignetted that, at high in-coupling efficiency, pupil
illuminations are nonetheless ensured at low ellipticity
downstream of the rod integrator. The in-coupling efficiency is

30   given by the ratio of the surface of the diaphragm opening to the

3

surface of the light spot. The ellipticity of a pupil
illumination is a scalar quantity and is determined in that the
ratio of the total intensities of the quadrants, which are
arranged about a horizontal axis, and the total intensities of
5   the quadrants, which are arranged about a vertical axis, is
formed. The quadrants are delimited by two straight lines which
intersect at the center of the pupil illumination and are
perpendicular to each other and each includes an angle of 45° to
the horizontal direction. In this way, the ellipticity is equal
10   to the ratio of a first integral (wherein there is an integration
over all points of the intensity distribution and whose x-values
are greater in magnitude than the y-values) and a second integral
(wherein there is an integration over all points of the intensity
distribution whose y-values are greater in magnitude than the
15   x-values) with the ellipticity being given by:

$$Ellipticity = \frac{\int\limits_{|x|>|y|} I(x,y)dxdy}{\int\limits_{|y|>|x|} I(x,y)dxdy} \cdot 100\%$$

The x-axis points in the horizontal direction and the y-axis
20   points in the vertical direction. Pupil illuminations without
ellipticity have an ellipticity equal to 1.0, that is 100%.

In order to achieve pupil illuminations with low ellipticity
at high in-coupling efficiency, the diaphragm has a diaphragm
opening which is symmetrical to a first symmetry axis which
25   points in the x-direction. In this way, it is achieved that the
light spot is vignetted symmetrically with respect to this
symmetry axis. The width of the diaphragm opening, which is
measured in the x-direction, is dependent upon the distance y
from the symmetry axis. The diaphragm opening has the lowest
30   width at y = 0.

The widths of the diaphragm opening are therefore greater or equal to the width at y = 0. Whereas the width continuously reduces to zero with an increasing distance y for a circular diaphragm opening, the diaphragm of the invention has a width at a distance y from the symmetry axis which is at least as great as the width at y = 0 or even greater. This diaphragm is mounted forward of the rod integrator whose rod width is measured in the x-direction and whose rod height is measured in the y-direction. As a rule, the rod width is greater than the rod height. In addition, the diameter of the light spot should be greater than the height of the rod. In this case, the light spot can be cut with the diaphragm so that the width of the light spot is about equal to the height of the light spot which results from vignetting at the upper or lower edge of the diaphragm opening or at the entry surface of the rod integrator depending upon whether the diaphragm opening or the rod integrator has a lesser height. If the angular distribution at the entry surface of the rod integrator is dependent upon the spacing from the optical axis, then the parts of the light spot can be vignetted in the x-direction which are cut in the y-direction by the diaphragm opening or the entry surface of the rod integrator. Without the diaphragm, elliptical pupil illuminations would result in a pupil plane downstream of the rod integrator.

With the diaphragm of the invention, the ellipticity of the pupil illumination downstream of the rod integrator can be significantly reduced. A pupil plane downstream of the integrator can, for example, be the exit pupil of the rod integrator or a pupil plane within an objective mounted downstream of the rod integrator in the direction of light. A

pupil plane forward of the rod integrator can, for example, be the entry pupil of the rod integrator or a pupil plane within an objective mounted forward of the rod integrator. If the pupil illumination ahead of the rod integrator is a so-called multipole

5   illumination, which is characterized by several illuminated regions separated from each other, then, with the use of the diaphragm according to the invention, the condition is achieved that the total intensities of the individual regions of the pupil illumination downstream of the rod integrator are almost in the

10   same ratio to each other as the total intensities of the individual regions of the pupil illumination forward of the rod integrator. Possible multipole illuminations are, for example, the dipole illumination with two separated regions or the quadrupole illumination with four separated regions.

15   If, in the following, reference is made to achieving pupil illuminations with reduced ellipticity or pupil illuminations without ellipticity, this means, with reference to the multipole illuminations, that the ratios of the total illuminations of the individual regions of the multipole illumination do not change

20   significantly with respect to each other or the ratios remain equal to each other.

           According to another feature of the invention, the diaphragm opening has an effective height H_{B1} which is virtually equal to the width at $y = 0$. A deviation of 10% is, however, tolerable.

25   With this condition, the vignetted light spot has an almost equal expansion in each of the x- and y-directions. If the diaphragm is mounted forward of a rod integrator, then the upper and lower limiting lines at the entry surface act as the upper and lower limiting lines of the diaphragm opening when the diaphragm

30   opening has a greater physical height than the entry surface of

6

the rod integrator. The effective height of the diaphragm is, in this case, given by the rod height. The phrase "the effective height H_{B1} of the diaphragm opening" will be understood in the following to be the value which is the lesser in the comparison of the physical height of the diaphragm opening and the rod height. A diaphragm whose diaphragm opening has the same physical height as the rod height causes the same effect with respect to the rod integrator as a diaphragm whose diaphragm opening is greater than the rod height.

As a rule, the angular distribution at the entry surface of the rod integrator is dependent only upon the distance from the optical axis. For this reason, one obtains a pupil illumination without ellipticity with a circular diaphragm opening whose diameter is equal to the rod height as long as no other factors influence the pupil illumination. Circular diaphragm openings have, however, the disadvantage that they vignette a significant portion of the light spot. A pupil illumination without ellipticity is likewise achieved with quadratic diaphragm openings. The in-coupling efficiency of a diaphragm having a quadratic diaphragm opening is greater by a factor $4/\pi$ than for a corresponding diaphragm with a circular diaphragm opening.

In order to further increase the in-coupling efficiency of the diaphragm, it is advantageous when the diaphragm opening has greater widths at the upper and lower edges than in the center at $y = 0$. The ratio of a second width B_2 at $y = H_{B1}/2$ to a first width at $y = 0$ should then be less than 2.0 and should especially lie between 1.4 and 1.7. The widths of the diaphragm opening should be greater than or equal to the first width B_1 and less than or equal to the second width B_2. This form of the diaphragm opening, which becomes wider upwardly and downwardly starting

7

from the first axis of symmetry, leads again to slightly elliptical pupil illuminations but also to a marked increase of the in-coupling efficiency. The maximum width at the upper edge of the diaphragm opening is dependent upon the tolerable ellipticity of the pupil illumination.

In an advantageous embodiment of the diaphragm, the diaphragm opening has a constant first width from $y = 0$ to a pregiven distance y_0 which is greater than one quarter of the diaphragm height and less than half the diaphragm height. Only starting from the pregiven distance y_0, does the width of the diaphragm opening increase up to the upper edge of the diaphragm opening. The widths can increase stepwise or continuously. For a continuous increase, the left edge or the right edge of the diaphragm opening between the pregiven distance y_0 and $y = H_{B1}/2$ can be described by a line, by a circular arc or by a polynomial.

For keeping the ellipticity of the pupil illumination within tolerable limits, it is advantageous when the pregiven distance y_0 is set into relationship to the first width B_1, to the second width B_2 and to the height H_{B1} of the diaphragm opening. Preferably, these quantities satisfy the following condition:

$$\frac{H_{B1} - \left(2 \cdot y_0\right)}{B_2 - B_1} > 0.6.$$

With this condition, it is achieved that the widths of the diaphragm opening do not increase too greatly toward the edge.

It is especially advantageous when the widths increase linearly between the pregiven distance y_0 and the upper edge of the diaphragm opening. In this way, triangularly-shaped additional areas are added to the central quadratic diaphragm opening at all four corners which areas increase the in-coupling

8

efficiency and introduce only a slight ellipticity of the pupil illumination. The edge lines between the pregiven distance y_0 and the upper edge of the diaphragm opening should enclose an angle to the y-axis between 0° and 60°, especially between 30°

5   and 60°, so that the ellipticity of the pupil illumination remains within tolerable limits.

In order to hold the ellipticity of the pupil illumination as low as possible, it is further advantageous that the diaphragm opening has a symmetry axis in the y-direction in addition to the

10   symmetry axis in the x-direction.

The width of the diaphragm opening at $y = 0$ should amount to between 2 mm and 30 mm, especially between 4 mm and 20 mm, in order to adapt to the dimensions of the rod integrators which are typical for the illumination system in microlithography.

15   The dimensions of the diaphragm opening are adapted to the downstream integrator. The distance between the diaphragm and the entry surface is given by the mechanical edge constraints of the frames of the components. The diaphragm can also be mounted forward of the rod integrator so as to be exchangeable. It is

20   also possible to place the diaphragm, for example, directly on the entry surface via a non-transparent coating. The diaphragm can, however, also be imaged on the entry surface of the rod integrator with an imaging optical system. On the side facing toward the rod integrator, the diaphragm can also have a coating

25   reflecting at the operating wavelength in order to be able to use the advantages described, for example, in United States Patent 5,473,408. The rod integrator can be configured as a hollow tube or a glass rod.

The application of the diaphragm and the integrator unit is

30   not limited to microlithographic projection exposure systems.

Rather, integrator units of this kind can be generally used in
illuminating systems which operate with rod integrators as
homogenizers and place high requirements on the pupil
illumination. For example, the use is also possible in
illuminating systems for wafer inspection systems, for exposure
systems for manufacturing flat panel displays, for projectors or
for microscopes.

Elliptical pupil illuminations occur primarily when the
entry surface of the rod integrator is rectangular and the light
spot (within which the angular distribution is dependent upon the
distance from the optical axis) is vignetted differently at the
entry surface in the x- and y-directions. The use of the
diaphragm of the invention is therefore advantageous when the
ratio of rod width and rod height amounts to at least 1.5. In
microlithographic projection exposure systems, side aspect ratios
in the range of 2:1, 4:1, up to 10:1 are typical. Additionally,
the width of the diaphragm opening at $y = 0$ should be about equal
to the rod height so that the light spot exhibits about the same
expansion in the x-direction and y-direction after the diaphragm.
The effective height of the diaphragm should be equal to the rod
height, that is, the physical height of the diaphragm should at
least be equal to the rod height or greater.

A condenser optic is usually mounted between the light
source and the integrator unit and this condenser optic includes
all optical components between the light source and the
integrator unit. The condenser optic collects the light of the
light source and focuses the same on the entry surface of the rod
integrator and there generates a light spot. The condenser
optics can include a zoom objective and/or axicon lenses in order
to influence the angular distribution at the entry surface of the

rod integrator and therefore also the form and expansion of the pupil illumination. The use of diffractive lenses is possible in the condenser optics. The optical components of the condenser optics usually have an optical effect rotationally symmetrical to

5   the optical axis. If the expansion of the light source and the emission characteristic of the light source are also rotationally symmetrical to the optical axis, then the form of the light spot is round and the angular distribution at the entry surface is only dependent upon the distance from the optical axis. If the

10   diameter of the light spot is greater than the rod height, then elliptical pupil illuminations occur after the rod integrator without diaphragm at an aspect ratio of the entry surface greater than 1:1. With the diaphragm described above, it is possible to achieve ellipticities less than 10%, especially less than 5% even

15   when the diameter of the light spot is 150% greater than the rod height.

       This reduction of the ellipticity is reached with simultaneously high in-coupling efficiency. The in-coupling efficiency is advantageously greater than with the use of a

20   diaphragm having a circular diaphragm opening whose diameter is equal to the rod height, especially greater by more than $4/\pi$ and especially greater by more than 1.3.

       The illumination system described above is advantageously used in microlithographic projection exposure systems which, in

25   addition to the illumination system, include a projection objective which images a mask carrying a structure onto a light-sensitive substrate. Here, resolutions of less than 300 nm are obtained so that especially high requirements are imposed on the pupil illumination.

30   Semiconductor components, inter alia, can be manufactured

with this microlithographic projection exposure system.

The invention is also directed to a method for exposing light-sensitive substrates as it is utilized, for example, in the manufacture of semiconductor components.

The light beam is generated by a light source, for example, a plasma light source or a mercury-vapor lamp. This light beam is at least partially taken up by a condenser optic. The condenser optic includes a first pupil plane wherein a first pupil illumination is generated by the light beam. This first pupil illumination exhibits no ellipticity when the condenser optics include optical components whose optical effects are rotationally symmetrical to the optical axis and when the light source exhibits an emission characteristic rotationally symmetric to the optical axis. The emission characteristic is given by the distribution of the ray angles to the optical axis.

The optical components of the condenser optic, which are mounted downstream of the first pupil plane, focus the light bundle on a light spot on an entry surface of a rod integrator.

The light spot is almost round when the light source has an expansion rotationally symmetrical to the optical axis. In contrast to the light spot, the entry surface of the rod integrator is not round but is, as a rule, rectangular. The entry surface includes a first expansion and a second expansion which are measured in mutually perpendicular directions. Especially in scanner systems, the second expansion is at least greater by a factor of 1.5 than the first expansion. Depending upon the expansion of the light source, the light spot can have a diameter which is greater than the first diameter and especially 150% and 400% greater than the first expansion. In this way, the light spot is differently vignetted at the entry

12

surface in the direction of the first expansion and in the direction of the second expansion. The angular distribution at the entry surface is, as a rule, dependent only on the distance from the optical axis. For this reason, this leads to the

5   situation that rays having different angles with respect to the optical axis arrive in the rod integrator in the direction of the first expansion and the second expansion.

The light spot is vignetted with a diaphragm which is mounted after the condenser optic and ahead of the rod

10   integrator. The diaphragm opening has a form which departs from the form of the light spot and the cross section of the entry surface of the rod integrator.

Within the rod integrator, the light beam is homogenized so that an almost homogeneous intensity distribution is generated at

15   the exit surface of the rod integrator. In the proximity of the exit surface, that is, at a defocusing of a few millimeters, a masking system is mounted which is imaged by an objective on a first field plane. With the masking system, the field illumination in the first field plane can be variably and sharply

20   delimited. The objective includes a second pupil plane having a second pupil illumination. Without the diaphragm forward of the rod integrator, the second pupil illumination would exhibit a marked ellipticity when the diameter of the light spot is significantly greater than the second expansion of the entry

25   surface of the rod integrator. The ellipticity can be reduced to less than 10%, especially less than 5%, with the diaphragm.

A mask carrying a structure is mounted in the first field plane and this mask is imaged by the projection objective onto a second field plane. A light sensitive substrate is mounted in

30   the second field plane and is exposed as soon as the light beam

13

impinges upon the light-sensitive substrate. Without the diaphragm, structures of the mask orientated in the direction of the first expansion of the entry surface and in the direction of the second expansion of the entry surface would be imaged at

5   differently large resolution values when the pupil illumination in the second pupil plane exhibits an ellipticity. Only with the diaphragm and the reduction of the ellipticity associated therewith is an imaging with homogeneous resolution values possible.

10   A diaphragm having the features mentioned in the description of the arrangement is especially used in the method.

The listing of the method steps is not final but gives only the steps which are required for reducing the ellipticity. Rather, additional method steps are to be used which are

15   generally known and usual for the exposure procedure.

Brief Description of the Drawings

The invention will now be described with reference to the drawings wherein:

FIG. 1 is a plan view of a diaphragm according to the

20   invention;

FIG. 2 is a schematic representation of a microlithographic projection exposure system; and,

FIG. 3 is a schematic showing the definition of the ellipticity of the pupil illumination.

25   Description of the Preferred Embodiments of the Invention

FIG. 1 shows an embodiment for a diaphragm 1 in accordance with the invention. The diaphragm 1 includes a diaphragm opening 3 which is symmetrical to a first symmetry axis 5 and symmetrical to a second symmetry axis 7. The origin of an x-y

30   coordinate system lies at the center of the diaphragm opening 3.

14

The first symmetry axis 5 points in the x-direction and the second symmetry axis 7 points in the y-direction. The height H_{BL} of the diaphragm opening 3 is 13 mm. The width of the diaphragm opening 3 is dependent upon the distance y from the symmetry axis 5. At y = 0, the width B_1 is B_1 = 13 mm in the embodiment of FIG. 1 and is equal to the height H_{BL} of the diaphragm opening. The diaphragm opening 3 has a constant width of 13 mm up to the elevation y_0 = 3.5 mm. The width of the diaphragm opening increases linearly between the elevation y_0 = 3.5 mm and the upper edge of the diaphragm opening 3. The width B_2 at the upper edge of the diaphragm opening 3 is B_2 = 21 mm at y = $H_{BL}/2$ = 6.5 mm so that the ratio of the width B_2 and the width B_1 is equal to 1.6. The edge line of the diaphragm opening 3 between the elevation y_0 and the upper edge of the diaphragm opening 3 encloses an angle of 53.1° with the y-axis. The ratio between the difference of the height H_{BL} and double the value of the elevation y_0 and the difference of the width B_2 and the width B_1 is:

$$\frac{H_{B1} - \left(2 \cdot y_0\right)}{B_2 - B_1} = \frac{13mm - (2 \cdot 3.5mm)}{21mm - 13mm} = 0.75.$$

In FIG. 2, the use of the diaphragm 1 is shown in a microlithographic projection exposure system. The diaphragm in FIG. 2 is identified by reference numeral 201. The microlithographic projection exposure system 215 includes the illumination system 213, the mask 219 carrying the structure, the projection objective 217 and the light-sensitive substrate 221. The light source 223 in the illuminating system 213 is a mercury discharge lamp and is mounted in one of the two focal points of an elliptical mirror 225 which collects the emitted light at the

15

second focal point 227.

The next objective 229 comprises: a first lens group 231; the concave first axicon lens 233; the convex second axicon lens 235; and, a second lens group 237. Positioning means 239 and 241 permit an axial displacement of the axicon lens 235 and an optical element of the second lens group 237. In this way, the distance of the axicon lenses (233, 235) to each other and, therefore, the annular field character of the pupil illumination in the pupil intermediate plane 243 can be changed and a zoom action for changing the diameter of the pupil illumination (that is, the degree of coherence σ) can be achieved. Embodiments for the objective 229 are shown in United States Patent 5,675,401 incorporated herein by reference. A second objective 245 follows the pupil intermediate plane 243. With the second objective 245, the light is focused on the diaphragm 201. The collector mirror 225, the objective 229 and the objective 245 conjointly form the condenser optic 210 which has exclusively optical components having optical effects rotationally symmetrical to the optical axis.

The condenser optic 210 images the light source 223 on the diaphragm 201. The diaphragm 201 is mounted directly ahead of the entry surface 247 of the rod integrator 211 which is configured as a quartz rod. The diaphragm 201 and the rod integrator 211 define the integrator unit 209.

The output of the rod integrator 211 is an intermediate field plane wherein a masking system (REMA) 249 is mounted. The following REMA-objective 251 images the masking system 249 on the mask 219 carrying the structure (reticle, lithographic input) and contains the following: a first lens group 253, a pupil plane 255, second and third lens groups (257 and 259) and a

16

deflecting mirror 261 therebetween. Embodiments for the REMA
objective 251 are disclosed in United States Patent 5,982,558 and
in United States Patent 6,366,410 incorporated herein by
reference.

5   The mask 219, which carries structure, is imaged by the
projection objective 217 on the light-sensitive substrate 221.
An embodiment for the projection objective 217 is disclosed in
United States patent application publication 2003/0007253
incorporated herein by reference. The mask 219 carrying the
10   structure as well as the light-sensitive substrate 221 are
carried by a positioning and change unit not shown which, in
addition to the exchange of elements, also permits scanning of
the elements during the exposure.

The diaphragm 201 is adapted to the dimensions of the rod
15   integrator 211. The entry surface 247 of the rod integrator 211
has a rod width B_{S1} = 28 mm and the rod height H_{S1} = 13 mm. The
rod width is measured in the x-direction and the rod height is
measured in the y-direction. The length of the rod integrator
is 800 mm in order to ensure an adequate homogenization of the
20   light. The width B_1 of the diaphragm 201 at y = 0 and the
height H_{BL} are thereby equal to the rod height H_{S1}. The
diaphragm 201 could also have a larger physical height because
the light spot in this case would be vignetted by the upper and
lower boundary lines of the entry surface 247. The distance of
25   the diaphragm 201 to the rod integrator 211 is 0.5 mm.

In the following, it will be shown how the use of the
diaphragm 201 influences the ellipticity of the pupil
illumination. For this purpose, the diaphragm 201 is first
removed from the illuminating system 213. In this embodiment,
30   the light arc of the light source 223 has a length of 4 mm and a

diameter of 6 mm. The light rays, which are emitted by the light source 223, have an angle of between 60° and 135° with respect to the optical axis OA. The light arc is imaged by the condenser optic 210 on the entry surface 247 and generates a light spot

5   having a maximum diameter of 41 mm which is thereby greater than the rod height by 315%. The rays have a maximum angle of 18° with reference to the optical axis OA. The diameter of the light spot and the ray angles at the entry surface are dependent upon the position of the zoom lenses and the axicon lenses (233, 235)

10   in the objective 229. In this example, the axicon lenses (233, 235) are closed and the objective 229 has a focal length of 77 mm. The rear focal plane of the objective 229 is close to the location of the second focal point 227 of the mirror 225, the forward focal plane is close to the location of

15   the pupil intermediate plane 243. The focal length of the objective 245 is 90 mm. The rearward focal point is close to the location of the pupil intermediate plane 243 and the forward focal point is close to the location of the diaphragm 201. The rod integrator 211 generates a homogeneous field illumination at

20   its exit surface and this field illumination is imaged by the REMA objective 251 on the mask 217 carrying structure. Following the field plane with the masking system 249 and after the lens group 253 having the focal length 123 mm, the pupil plane 255 of the REMA objective 251 follows. The pupil illumination is viewed

25   in the pupil plane 255 as intensity distribution $I(x,y)$. The rearward focal plane of the lens group 253 is disposed close to the location of the masking system 249 and the forward focal plane is close to the location of the pupil plane 255.

     The definition of the ellipticity of the pupil illumination is shown in FIG. 3. The pupil illumination 375 is not

30

18

homogeneous as shown schematically in FIG. 3; rather, the pupil illumination exhibits a grating of separated light spots because of the coverage of the entry surface 247 of the rod integrator 211 which is not complete in the y-direction. For

5   determining the ellipticity, the total intensities are determined in the four quadrants (363, 365, 367, 369). The quadrants are bounded by the straight lines 371 and 373 which are each at 45° to the y-axis. The ellipticity is now equal to the quotient from the total intensities in the quadrants 363 and 367 and the total

10   intensities in the quadrants 365 and 369:

$$Ellipticity = \frac{\int\limits_{363} I(x,y)dxdy + \int\limits_{367} I(x,y)dxdy}{\int\limits_{365} I(x,y)dxdy + \int\limits_{369} I(x,y)dxdy} \cdot 100\%$$

Without the use of the diaphragm, the ellipticity of the

15   pupil illumination in the pupil plane 255 is 19%. If a circular diaphragm is mounted ahead of the rod integrator 211, which has the diameter equal to the rod height $H_{SI} = 13$ mm, then the ellipticity vanishes. With the use of the circular diaphragm, one loses, however, 48% of the total intensity compared to an

20   integrator unit 209 which has no diaphragm ahead of the entry surface. The in-coupling efficiency of the circular diaphragm is 10.1%.

The ellipticity of the pupil illumination likewise vanishes with a quadratic diaphragm whose height and width are equal to

25   the rod height $H_{S1} = 13$ mm. With a quadratic diaphragm, one loses only 37% of the total intensity compared to an integrator unit 209 without diaphragm. The in-coupling efficiency of the quadratic diaphragm is 12.8%.

With the diaphragm 201, the ellipticity of the pupil

30   illumination is 2.5%. The ellipticity is significantly lower and

19

has a more tolerable value compared to an integrator unit 209 without diaphragm (ellipticity 19%). With the diaphragm 201, one loses only 32% of the total intensity compared to an integration unit 209 without diaphragm. The in-coupling efficiency of the diaphragm 201 is 14.6%. Compared to a circular diaphragm, the in-coupling efficiency is greater by a factor of 1.45. The total intensity is greater by a factor of 1.3 than for an integrator unit having a circular diaphragm.

Starting from the diaphragm 201, the edge line of the diaphragm opening can be so modified that, for increased requirements as to the ellipticity of the pupil illumination, tolerable values for the ellipticity result. For example, the inclination angle of the edge line can be reduced between the elevation y_0 and the upper edge of the diaphragm opening. It is also possible to increase the value for the elevation y_0.

Lower values for the ellipticity result also when the edge line is not linear between the elevation y_0 and the upper edge of the diaphragm opening; rather, it forms an arc so that the widths of the diaphragm opening in this region are less than in the diaphragm 201.

With the embodiments for a diaphragm, which is mounted forward of a rod integrator, it has been shown that it is possible, at high efficiency, to achieve pupil illuminations which exhibit almost no ellipticity.

It is understood that the foregoing description is that of the preferred embodiments of the invention and that various changes and modifications may be made thereto without departing from the spirit and scope of the invention as defined in the appended claims.